INVESTIGATION ON MECHANICAL BEHAVIOR OF CONCRETE WITH FIBERS MADE OF RECYCLED MATERIALS

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Abstract

Application of recycled materials in the construction industry is important for sustainable development. Advantagesof concrete with recycled short fibersare recycled of waste resources and protection of environmental containment. Also it brings new types of applications and enables saving sources of natural aggregate.

To investigate the effects of fiber quantity on mechanical properties of recycled short fiber reinforced concrete and identify the suitable materials to enhance the mechanical properties of concrete this experimental program is planned. Fibers made of recycled materials, including coconut coir fiber, fibers from polyethylene terephthalate (PET) bottles and steel fibers were used with different fiber contents.

Compressive strength, tensile strength, flexural strength and density test were done for plain concrete of concrete mix and fiber reinforced concrete to determine the mechanical properties of recycled short fiber reinforced concrete.

Key words: Fiber reinforced concrete,Recycled short fibers, Durability, PET fiber, Steel fiber

1. Introduction

Concrete is the most frequently used construction material in the world. However, concrete is strong in compression but it has low tensile strength, low ductility, and low energy absorption. Therefore improving concrete toughness and reducing the amount of defects in concrete would lead to better concrete performance. An effective way to enhance the mechanical properties of concrete is by adding a small fraction of short fibers to the concrete mix during mixing.

After extensive studies it is widely reported that such fiber reinforced concrete (FRC) can significantly improve the tensile properties of concrete (Keer, 1984; Wan et al, 1987; Bentur and Mindess, 1990). Other benefits of FRC include improved fatigue strength and wear resistance. By using FRC instead of conventional concrete, section thickness can be reduced and cracking can be effectively controlled, resulting in lighter structures with a longer life expectancy (Wang, Wu & Li, 2000).

FRC is used in industrial floors, tunneling, mining, security structures, heavy duty pavements, slab types members and runways of airport where conventional reinforcement are impractical.

Many types of fibers have been used for concrete and some are widely available for commercial applications. They include steel, glass, natural cellulose, carbon, nylon, and polypropylene, among others.

Concrete with fibers from recycled materials is considered to have generally worse mechanical properties than common concrete. But the idea to add fibers to a concrete mixture may change material properties of such concrete, improve behavior and bring about new types of applications as virgin fibers. Concrete with recycled short fibers can be considered as optimal structural concrete for various applications as mentioned above.

Waste generated from pre-and-post consumer waste is becoming a concerning issue both with the manufacturers and the disposal authorities. Concrete with recycled short fibers make positive effects are recycled of waste resources and protection of environmental containment. Also it is a provision of an alternative material for the construction industry.

Waste PET bottles had been reworked for drinking bottles by melting fusion, which turned out to be too costly. Therefore waste PET bottles will be insured to recycling as short fibers to reduce the rework cost. If waste PET bottles will be reused as short fibers for concrete, positive effects are expected on the recycling of waste resources and the protection of environmental containment.

Figure 1: Wastes of PET bottles and Steel

Certain quantity of fibers can be beneficial for enhancing the properties of plain concrete. But it is not necessary that all properties will be improved, the addition of fibers may increase certain properties and at the same time may decrease other ones. Therefore the fibers in appropriate quantity should be selected.

To investigate the effects of fiber quantity on mechanical properties of recycled short fiber reinforced concrete and identify the suitable materials to enhance the mechanical properties of concrete experimental program is planned. Recycled fibers, including coconut coir fiber, fiber from PET bottles, PVC fiber and steel fibers were used with different fiber contents.

The main purpose of the research is to study the effect of recycled short fibers to enhance the mechanical properties of concrete. The specific aims of the research is to study the effect of fiber fraction and size on mechanical behavior of coir fiber reinforced concrete, fiber reinforced concrete with recycled PET bottles and steel fiber reinforced concrete,Identify suitable materials to enhance the mechanical properties of concrete and prepare guidelines and specifications for future requirements.

2. Methodology

2.1 Raw materials

Ordinary Portland Cement (OPC), fine aggregate, coarse aggregate (maximum size of aggregate-20mm),water cement ratio of 0.62, coconut coir fiber, steel fiber and PET fiber were used for preparation of plain concrete and fiber reinforced concrete samples. Mixture properties of used recycled short fibers are shown in Table 1.

Table 1: Properties of recycled short fibers

Fiber Type	*Diameter (mm)*	*Length (mm)*	*Density (kg/m^3)*
Coconut Coir Fiber	*0.60*	*50*	*600*
Steel Fiber	*0.75*	*60*	*7850*
PET Fiber	*0.91*	*55*	*1235*
	0.56	*55*	*1370*

2.2 Preparation of samples

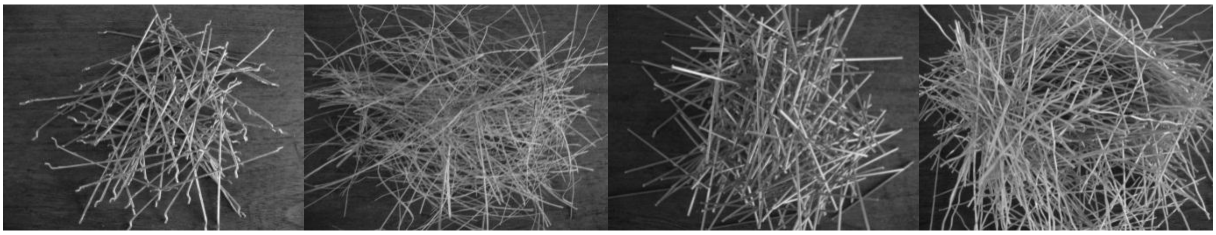
Recycled short fibers of coconut coir fiber, steel fiber and PET fiber were used for fiber reinforced concrete to investigate the mechanical properties of plain concrete (PC) and FRC with different volume fraction.

The mix design for plain concrete and FRC is as shown in Table 2.

Table 2: The mix design for plain concrete of one mixture (0.061m^3)

Grade of Concrete	*G- 25/20*
Workability of mix (Slump)	*(60-180 mm)*
Water- cement ratio	*0.62*
Fine Aggregate Type	*River sand*
Free water content	*14.1 kg*
Cement Content	*22.6 kg*
Coarse aggregate content	*63.8 kg*
Fine aggregate content	*56.6 kg*

In this study, volumefraction 1, 3 and 6 % on fine aggregate replaced with coconut coir fiber which is havingequal length of 50mm and that was used for coconut coir fiber reinforced concrete (CC-FRC).



(a) (b) (c) (d)

Figure 2: Used recycled short fibers: Steel(a),Coconut coir(b), PET(.91mm)(c)and PET(.56mm)(d)

Thevolume fraction 0.25, 0.5 and 0.75 % on fine aggregate replaced with the steel fiber which is havingequal length of 60mmandthat was used for steel fiber reinforced concrete (S-FRC).The volume fraction 1, 2 and 3 % on fine aggregate replaced with PET fiberwhich is having equal length of 55mmand that wasused for PET fiber reinforced concrete (PET-FRC).

A concrete mixer of rotatingpantype was used in preparing the concrete mixtures. Coarse aggregate and fine aggregate were fed in the mixer along withpart of mixingwater, and the mixer was operated. After mixing aggregate, cement was put and mixed for several minutes. Next,short fibers recycled materials were gradually fed with the balance amount of water, while mixing was continued.

(a) (b)

Figure 3: Mixing of recycled PET fibers (a) and measurement of slump (b)

2.3Testing procedure

In this study compressive strength, splitting tensile (STS) strength, flexural strength and density were investigated of concrete mixers with different volume fraction.

I. Compressive strength of concrete

The compressive strength of concrete was investigated by using the concrete crushing machine available in the Construction and Materials Laboratory. The three specimenof cube with the size of 150 x 150 x 150 mm, were tested for each addition and replacement of different fiber fraction at 3 or 5, 14, and 28 day age. Average compressive strength of plain concrete and fiber reinforced concrete at each age were determined by averaging three corresponding strength measurements according to BS 1881: Part 121: 1993.

II. Tensile strength of concrete

The tensile strength of concrete was determined using standard cylinders 150mm diameter and 300mm height according to BS 1881: 114. A set of three specimenfor each specimen was produced and spilt tensile strength was investigated by using the crushing machine available in the Construction and Materials Laboratory.

III. Flexural strength of concrete

The flexural strength concrete was determined according to BS 1881: 5 1970. A set of three prismspecimenof 100mm in wide, 100mm in height and 500mm in length were prepared for each volume fraction of different recycle fiber.

IV. Density test of concrete

Density of the concrete mixer of sampleswas carried out by measuring its mass and volume for different days of curing. The specimen size for the test was 150x 150x150mm according to the BS 1881: 114.

3. TestResult and Discussion

3.1 Coconut coir fiber

The investigated properties, compressive strength, splitting tensile strength flexural strength and workability are shown in Tables 4, 5 and Figures 5, 6 for PC and CCFRC.

Table 4: Compressive strength of PC and CC-FRC

	5 days		14 days		28 days	
Sample	*Ave:Com:Strength(MPa)*	*Ave: Density (kgm^{3})*	*Ave: Com: Strength(MPa)*	*Ave: Density (kgm^{-3})*	*Ave:Com:Strength(MPa)*	*Ave: Density (kgm^{-3})*
PC	*19.713*	*2400*	*31.820*	*2390*	*33.930*	*2351*
1% CC-FRC	*15.860*	*2395*	*24.330*	*2356*	*28.833*	*2331*
3% CC-FRC	*13.600*	*2350*	*22.443*	*2336*	*25.533*	*2267*
6% CC-FRC	*15.033*	*2360*	*24.923*	*2365*	*28.560*	*2311*

Table 5: Average tensile strength and flexural strength of PC and CC-FRC

Sample	*Average Tensile Strength (MPa)*	*Average Flexural Strength (MPa)*	*Slump (mm)*
PC	*1.860*	*5.643*	*190*
1% CC-FRC	*1.981*	*6.011*	*140*
3% CC-FRC	*2.249*	*6.256*	*105*
6% CC-FRC	*2.188*	*6.747*	*70*

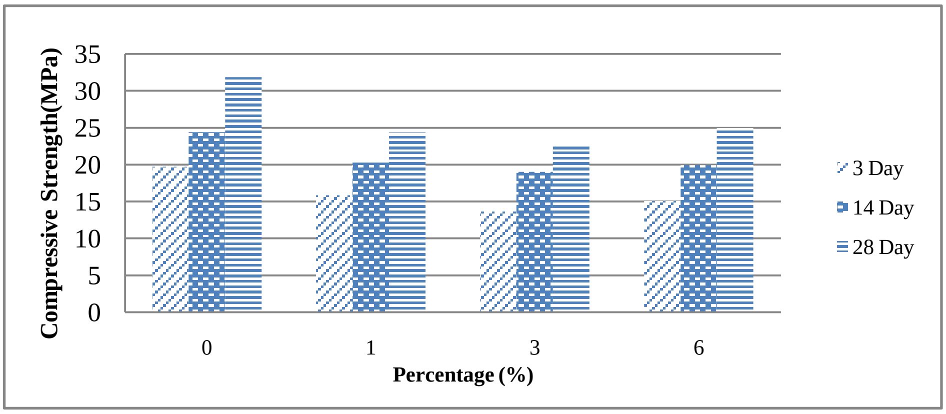
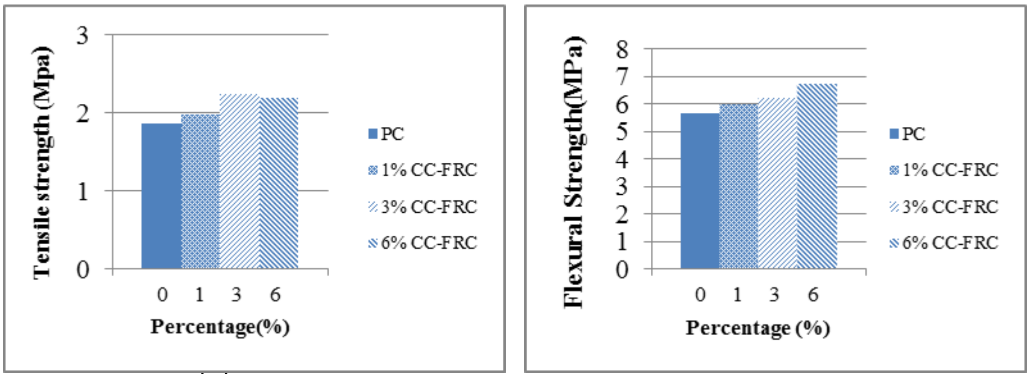


Figure 5: Average Compressive Strength of PC and CC-FRC



(a) (b)

Figure 6: Average Tensile Strength (a) Flexural Strength (b) of PC and CC-FRC

There is a slight decrease in compressive strength and an increase in corresponding flexural strength and splitting tensile strength (STS) of CC-FRC as compared to that of PC. It can be noted that CCFRC with 1 % fiber fraction showed higher compressive strength and 6% fiber fraction showed better results of split tensile strength and flexural strength among other volume fractions.

3.2 Steel Fiber

The investigated mechanical properties, compressive strength, splitting tensile strength, flexural strength and workability are shown in Tables 6, 7 and Figures7, 8 for PC and SFRC.

Table 6: Compressive strength of PC and SFRC

	5 days		14 days		28 days	
Sample	*Ave: Com: Strength(MPa)*	*Ave: Density(kgm-3)*	*Average Compressive Strength*	*Ave: Density (kgm-3)*	*Average Compressive Strength*	*Ave: Density (kgm-3)*
PC	*19.127*	*2415*	*29.53*	*2410*	*30.827*	*2405*
0.25% SFRC	*14.633*	*2380*	*25.78*	*2395*	*29.383*	*2380*
0.5% SFRC	*11.567*	*2365*	*19.74*	*2360*	*22.490*	*2370*
0.75% SFRC	*11.023*	*2380*	*20.28*	*2395*	*21.950*	*2390*

Table 7: Average tensile strength and flexural strength of PC and SFRC

Sample	*Average Tensile Strength (MPa)*	*Average Flexural Strength (MPa)*	*Slump(mm)*
PC	*2.274*	*7.238*	*120*
0.25% SFRC	*1.977*	*6.992*	*110*
0.5% SFRC	*1.770*	*5.520*	*95*
0.75% SFRC	*1.783*	*5.643*	*80*

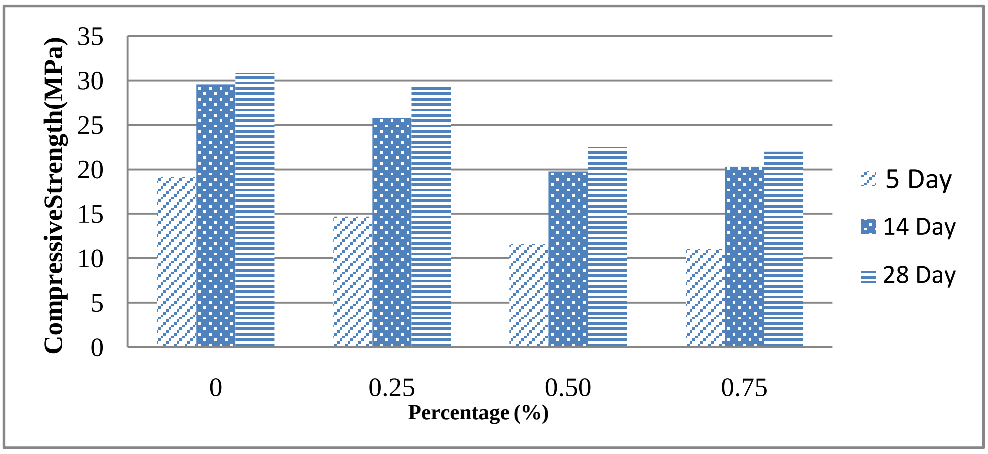
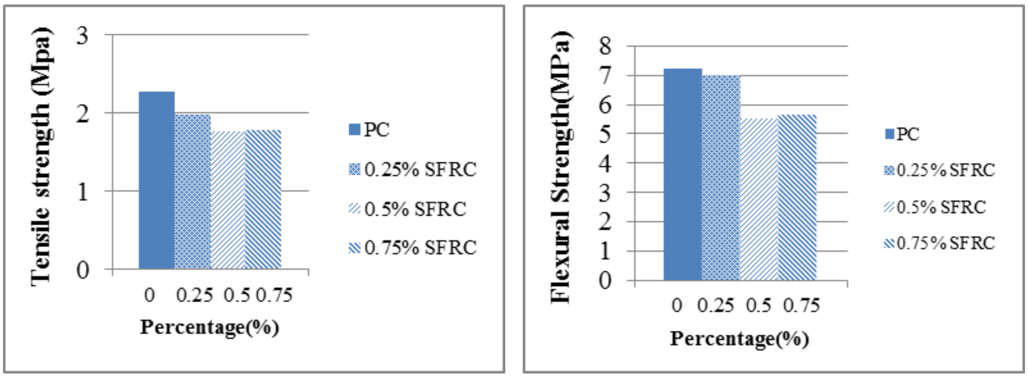


Figure 7: Average Compressive Strength of PC and SFRC



(a) (b)

Figure 8: Average Tensile Strength (a) Flexural strength (b) of PC and SFRC

There is a slight decrease in compressive strength, flexural strength and splitting tensile strength (STS) of S-FRC as compared to PC. Compressive strength is decreased with increasing of volume fraction of steel. It can be noted that S-FRC with 0.25 % fiber fraction showed better results of compressive strength, split tensile strength and flexural strength among other volume fractions.

3.3 PET Fiber

In this study, two type of diameter PETfiber (0.91, 0.56mm) were used for PET-FRC. The test results of compressive strength, splitting tensile strength, flexural strength and workability are shown in Tables8 to11 and Figures9 to12 for PC and PET-FRC.

Table 8: Compressive strength of PC and PET -FRC (0.91mm)

	3 days		*14 days*		*28 days*	
Sample	*Ave: Com: Strength(MPa)*	*Ave: Density (kgm^3)*	*Ave: Com: Strength(MPa)*	*Ave: Density (kgm^3)*	*Ave: Com: Strength(MPa)*	*Ave: Density (kgm^3)*
PC	*9.86*	*2385*	*21.74*	*2385*	*31.21*	*2370*
1% PET-FRC	*8.98*	*2360*	*18.15*	*2375*	*22.65*	*2365*
2% PET-FRC	*8.65*	*2375*	*17.33*	*2375*	*21.80*	*2370*
3% PET-FRC	*9.38*	*2375*	*18.79*	*2375*	*21.67*	*2361*

Table 9: Average tensile strength and flexural strength of PC and PET -FRC (0.91mm)

Sample	*Average Tensile Strength (MPa)*	*Average Flexural Strength (MPa)*	*Slump(mm)*
PC	*2.051*	*6.321*	*170*
1% PET-FRC	*1.627*	*5.765*	*150*
2% PET-FRC	*1.649*	*6.133*	*110*
3% PET-FRC	*2.023*	*6.011*	*70*

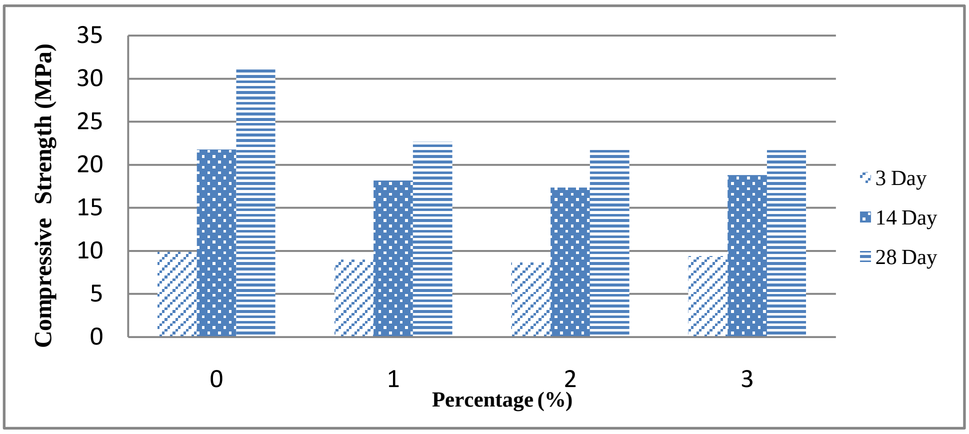
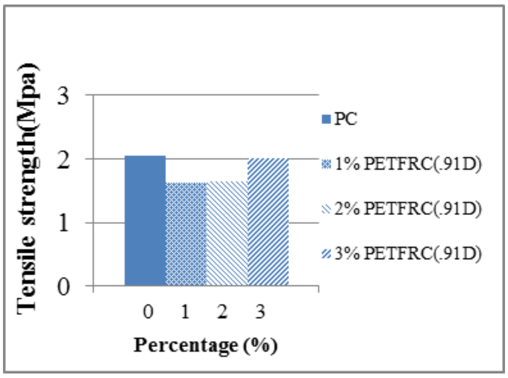
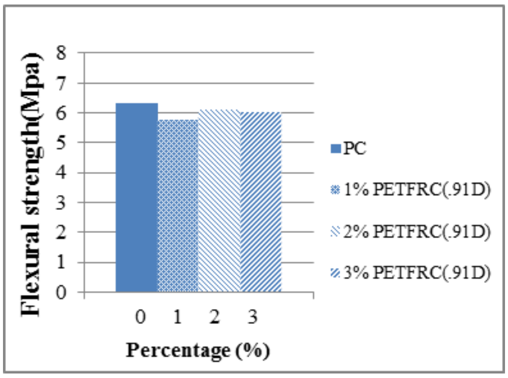


Figure 9: Average Compressive Strengthof PC and PET –FRC (0.91mm)



(a)



(b)

Figure 10: Average Flexural Strength (a) Slump (b) of PC and PET-FRC (0.91mm)

There is a slight decrease in compressive strength, flexural strength, splitting tensile strength (STS) and workability of PET-FRC as compared to PC. It can be noted that PET-FRC with 3 % fiber fraction showed better results of compressive strength and split tensile strength and 2% fiber fraction showed better results of and flexural strength among other volume fractions.

Table 10: Compressive strength of PC and PET (0.56mm)-FRC

	3 days		*14 days*		*28 days*	
Sample	*Ave: Com: Strength(MPa)*	*Ave: Density (kgm^3)*	*Ave: Com: Strength(MPa)*	*Ave: Density (kgm^3)*	*Ave: Com: Strength(MPa)*	*Ave: Density (kgm^3)*
PC	*9.75*	*2375*	*19.52*	*2370*	*25.57*	*2370*
1% PET-FRC	*9.66*	*2385*	*19.42*	*2390*	*24.31*	*2410*
2% PET-FRC	*9.08*	*2365*	*17.53*	*2351*	*21.6*	*2351*
3% PET-FRC	*8.00*	*2326*	*16.92*	*2326*	*21.08*	*2321*

Table 11: Average tensile strength and flexural strength of PC and PET (0.56)-FRC

Sample	*Average Tensile Strength (MPa)*	*Average Flexural Strength (MPa)*	*Slump(mm)*
PC	*1.744*	*5.765*	*150*
1% PET-FRC	*1.829*	*6.011*	*130*
2% PET-FRC	*1.807*	*5.888*	*100*
3% PET-FRC	*1.744*	*5.765*	*85*

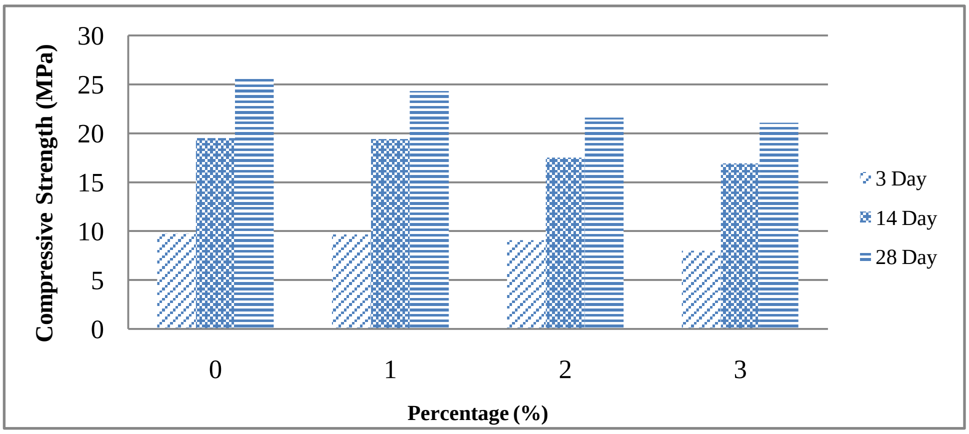
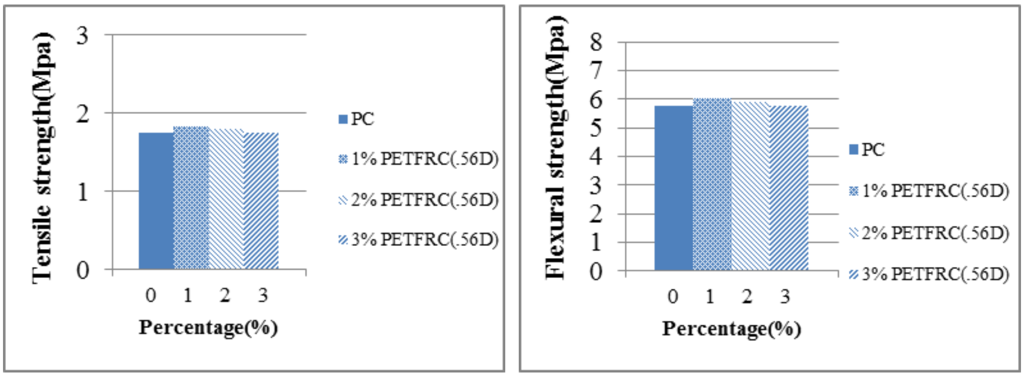


Figure 11: Average Compressive Strength of PC and PET (0.56mm)-FRC



(a) (b)

Figure 12: Average Tensile Strength (a) Flexural Strength (b) of PC and PET-FRC (.56mm)

There is a slight decrease in compressive strength of PET fiber reinforced concrete (PET-FRC (.56Φ)) when compared to plain concrete (PC). There is a significant improvement in the flexural strength and split tensile strength with 1 % and 2% Volume fractions. No significant improvement in flexural strength and split tensile strength is observed for 3% volume fraction.

4. Conclusions

The challenge in the 21st century is to reduce the creation of pre-and-post consumer waste. Concrete with recycled short fibers make positive effects are recycled of waste resources and protection of environmental containment. Also it is a provision of an alternative material for the construction industry.

As demonstrated in many studies, some of the recycled fibrous materials can used to enhance the mechanical properties of concrete. This was discussed in different studies on recycled short fibers of various sources including PET bottles, steel and coconut coir in comparison with commercially available fibers often found to be effective in improving the toughness, flexural strength and split tensile strength.

Reduction of the workability of FRC is a major problem because of the presence of fibers.In the compressive and split tensile test, the plain concrete specimens failed in a brittle manner and shattered into pieces. In contrast, after reaching the peak load, all the FRC samples still remained as an integral piece, with fibers holding the concrete matrices tightly together.

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